

Validation of CFSv2 Model Behavior – Land-Atmosphere Interactions and the Hydrologic Cycle

Paul Dirmeyer^{1,2} & Ahmed Tawfik²

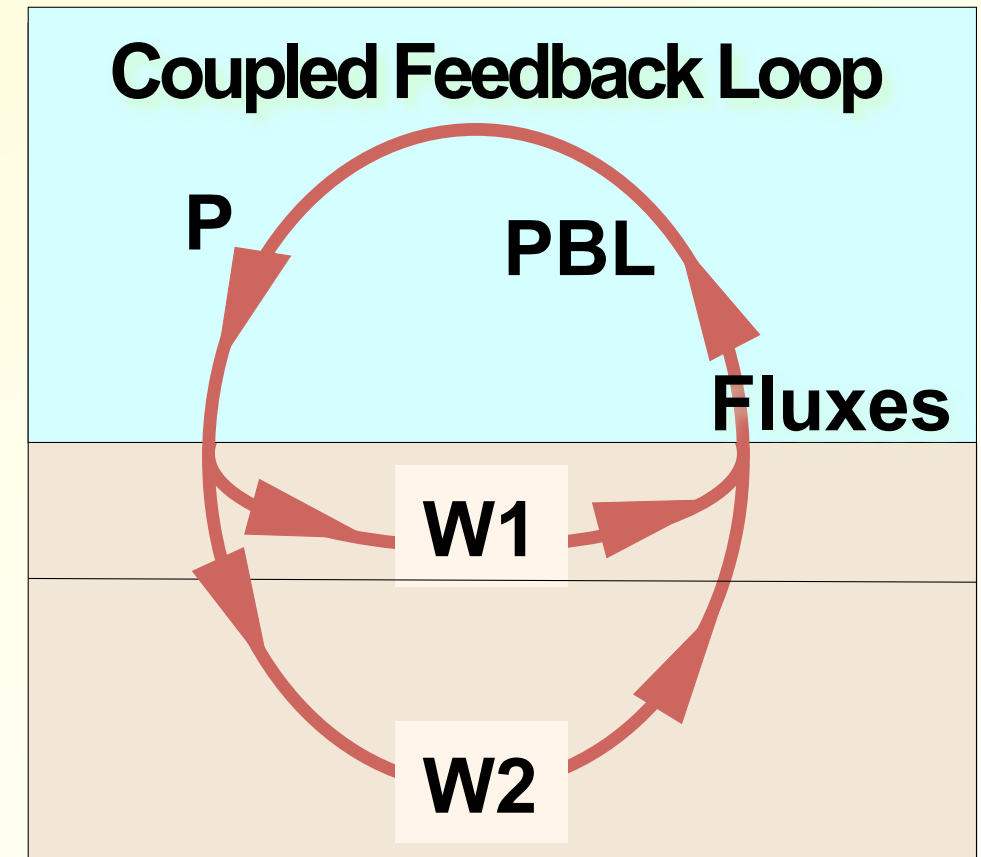
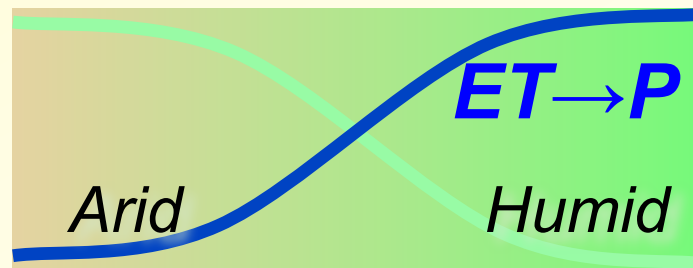
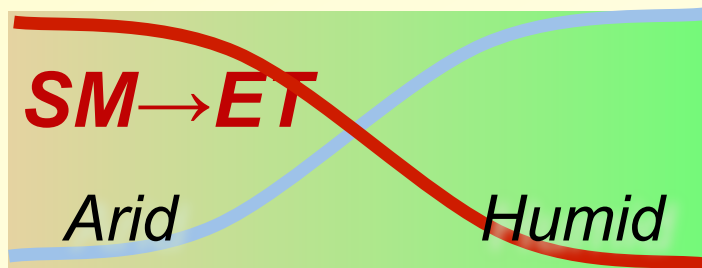
¹George Mason University

²Center for Ocean-Land Atmosphere Studies

Theory: L-A feedback stands on 2 legs

$$\Delta P \rightarrow \Delta SM \rightarrow \Delta \text{Fluxes} \rightarrow \Delta \text{PBL} \rightarrow \Delta P$$

Feedback path: **Terrestrial leg** **Atmospheric leg**



- **Terrestrial** – When/where does soil moisture (vegetation, snow, etc.) control the partitioning of net radiation into sensible and latent heat fluxes?
- **Atmosphere** – When/where do surface fluxes significantly affect boundary layer growth, clouds and precipitation?

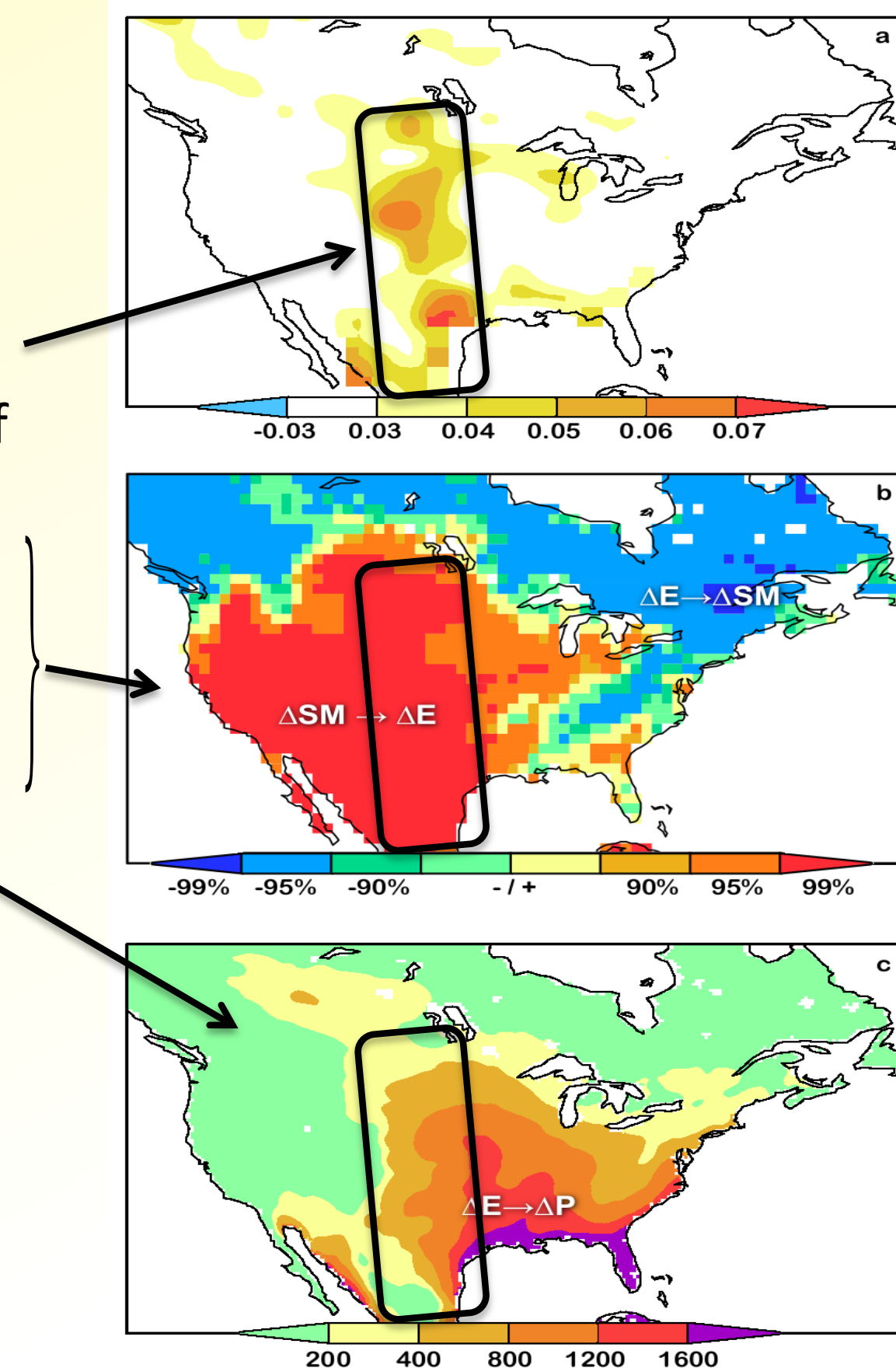
The Two Legs: Example

- GLACE coupling strength for summer soil moisture to rainfall corresponds to regions where there are both of these factors:
- High correlation between daily soil moisture and evapotranspiration during summer [from the GSWP multi-model analysis, units are significance thresholds; *middle*], and
- High CAPE [from the North American Regional Reanalysis, J/kg; *bottom*]

$$\Delta P \Rightarrow \underbrace{\Delta SM \rightarrow \Delta Flux}_{\text{Terrestrial leg}} \rightarrow \underbrace{\Delta P}_{\text{Atmospheric leg}}$$

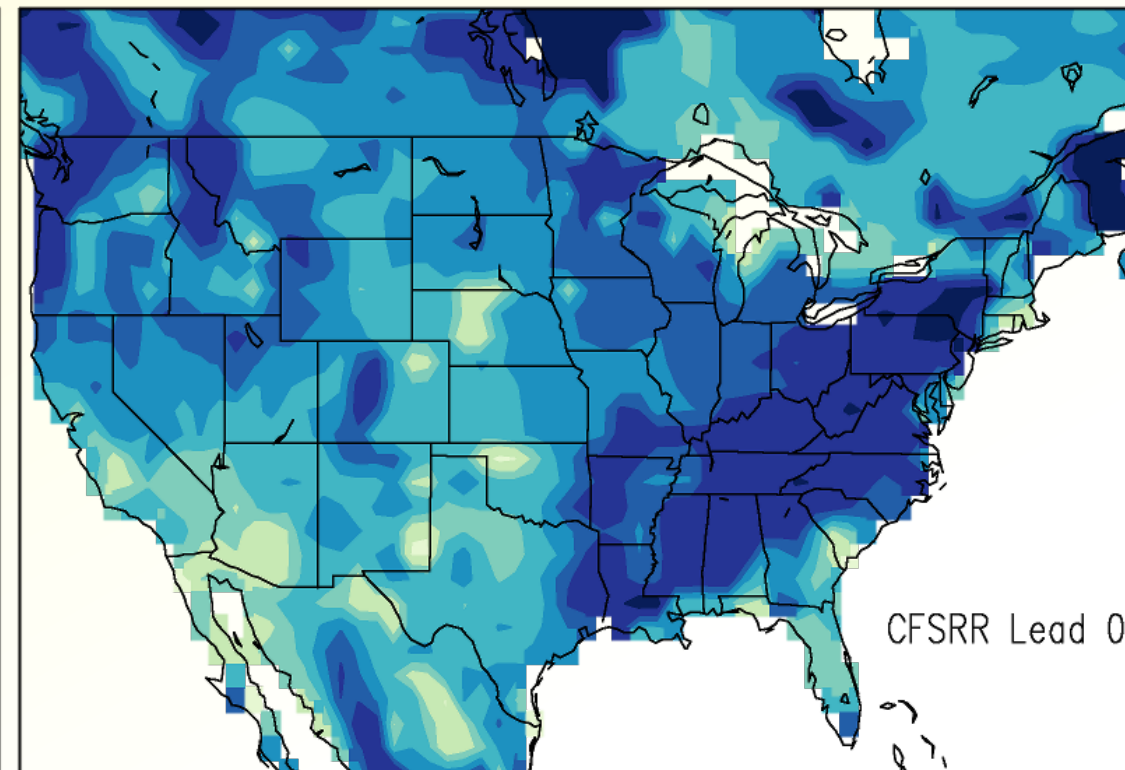
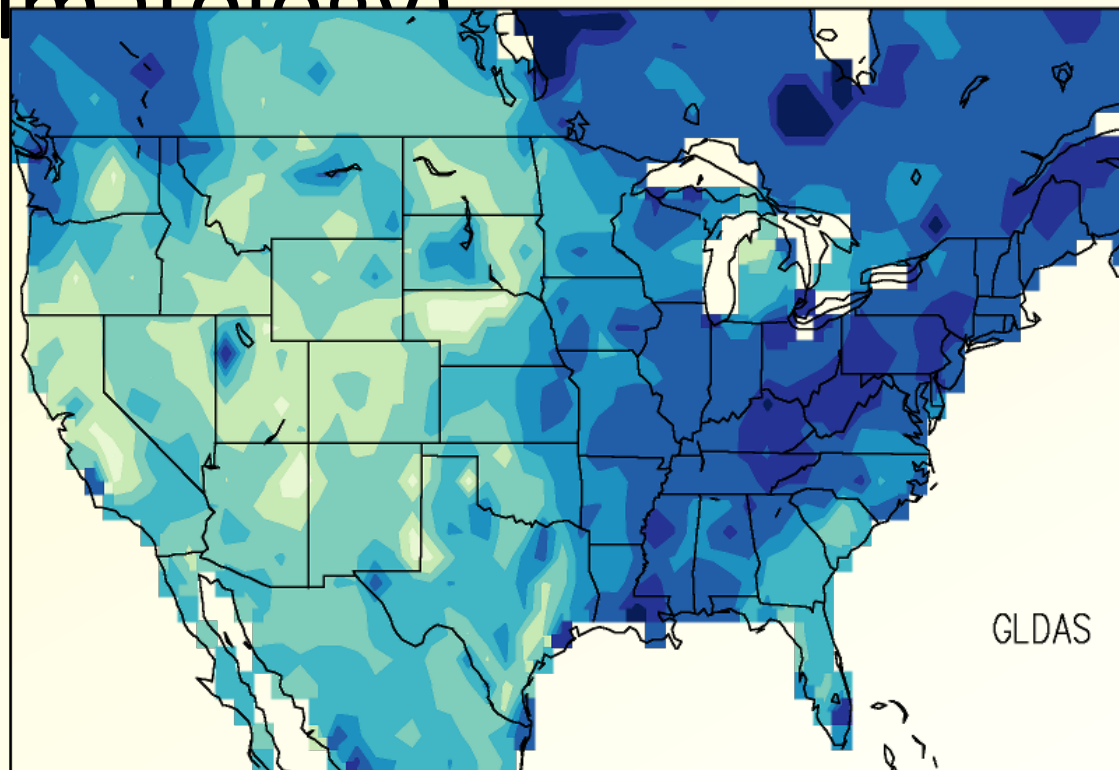
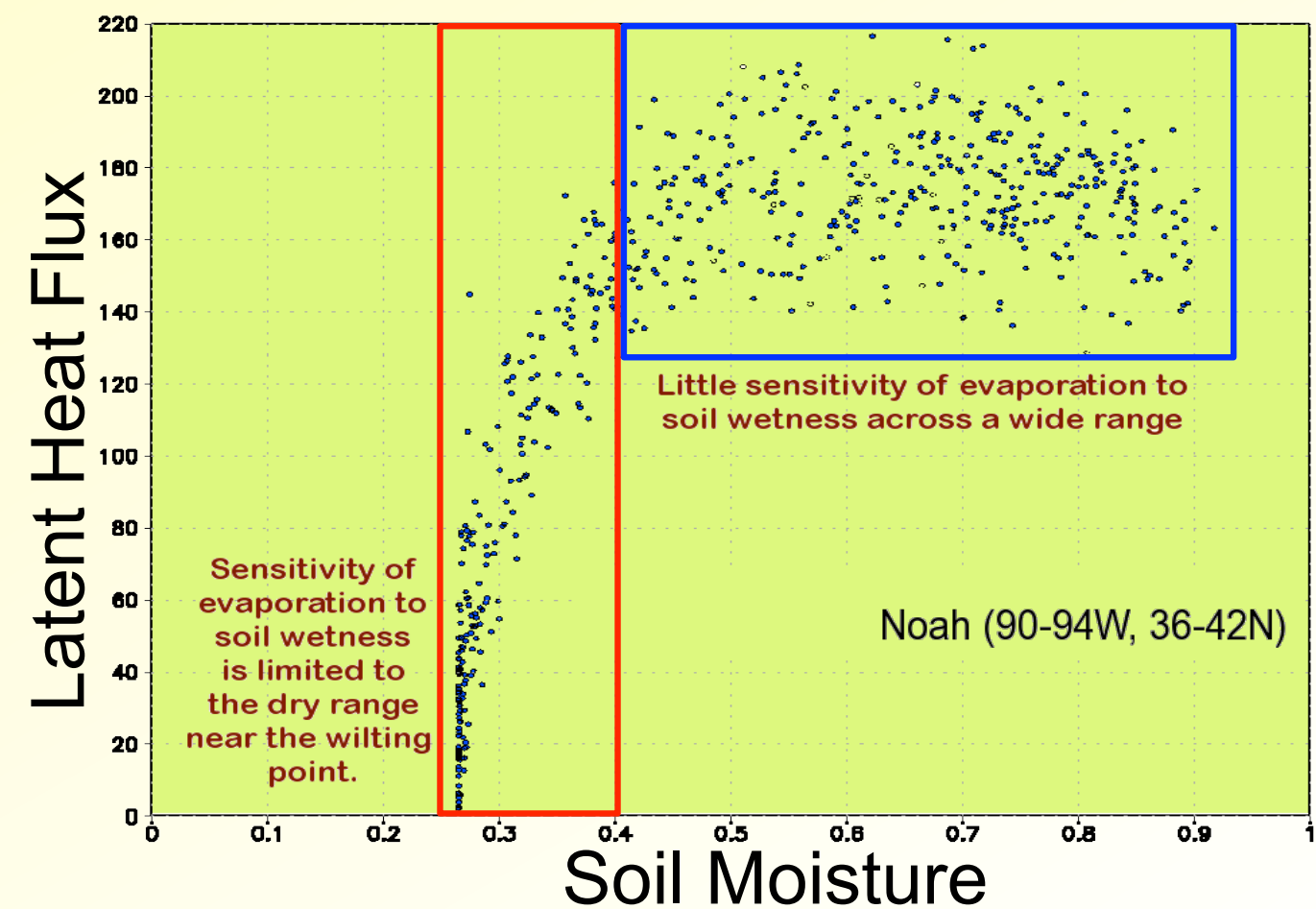
Feedback path: Terrestrial leg

Atmospheric leg



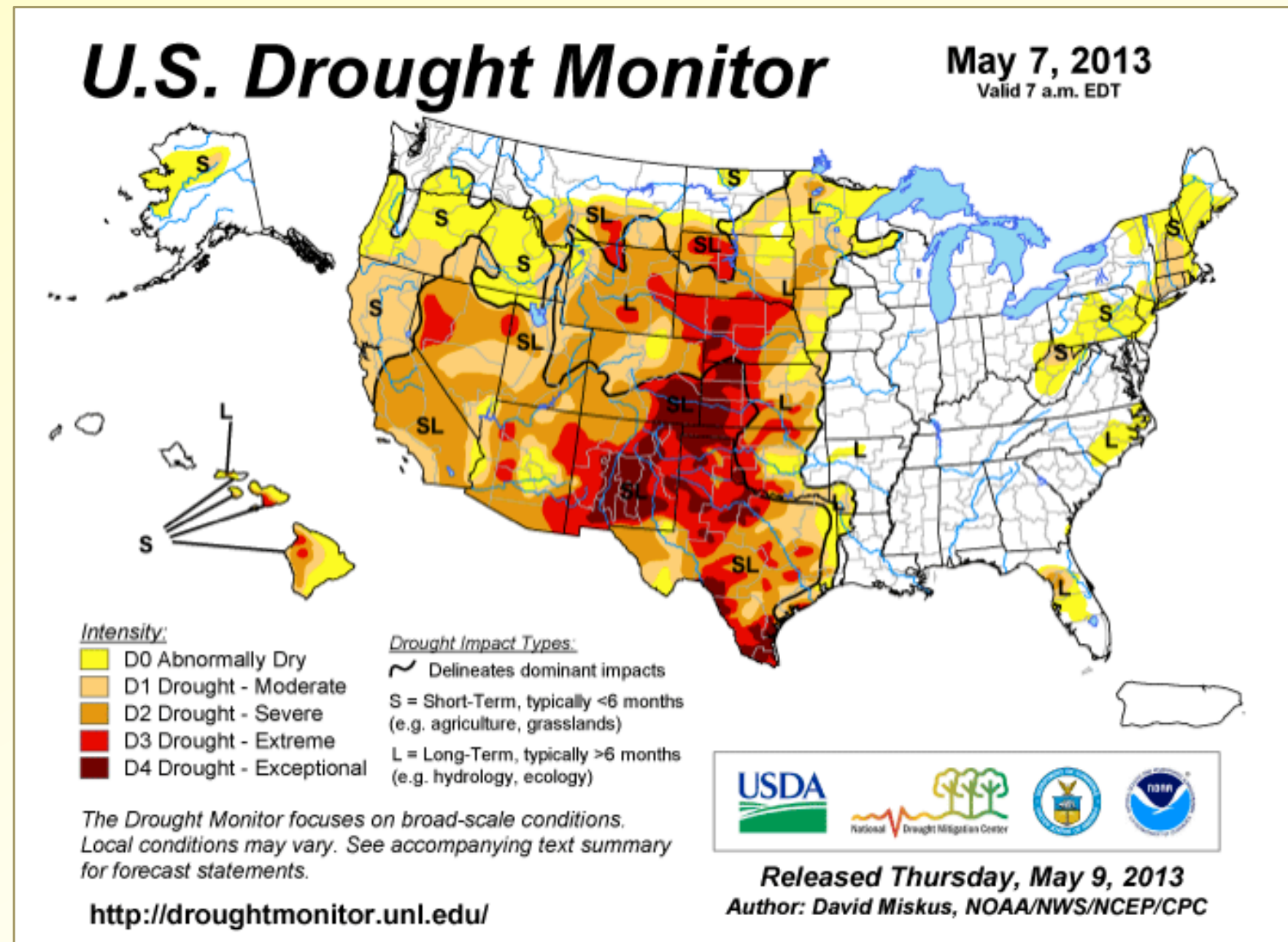
Noah and GFS

- Flux sensitivity is at the dry end of soil moisture range
- West-east gradient (below: Noah JJA 10-40cm layer climatology)



2013 Situation

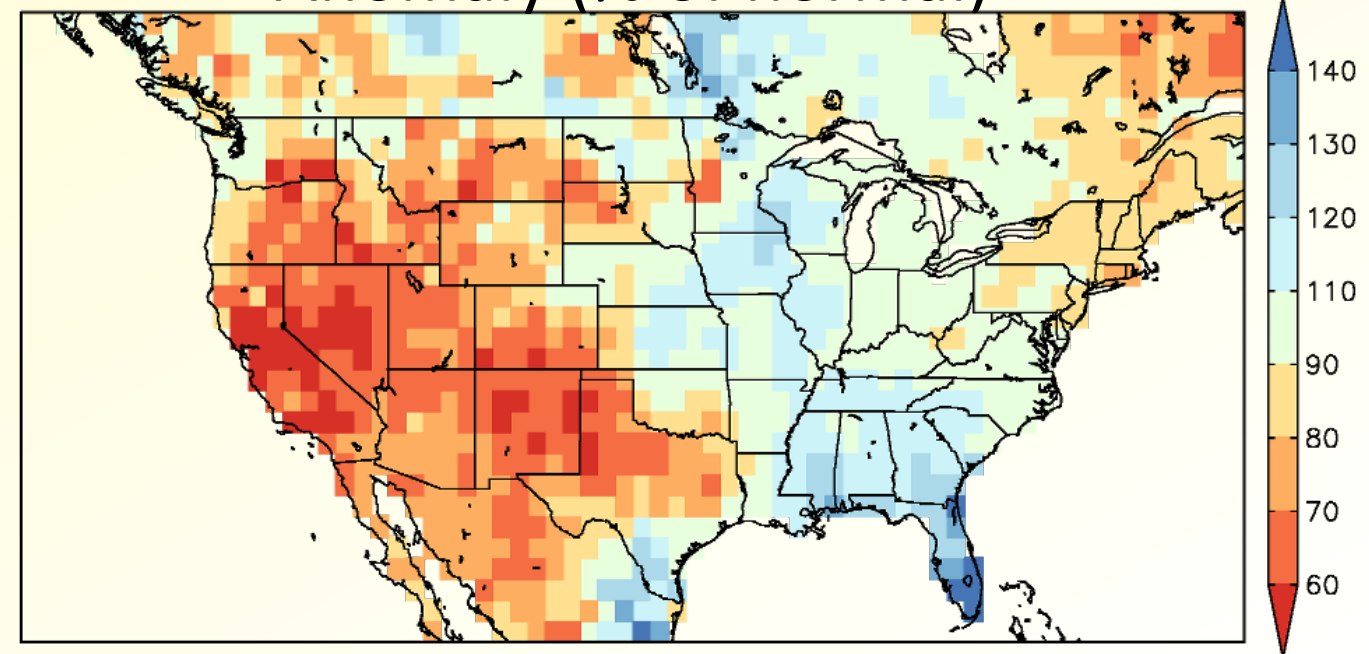
- Western half of the lower-48 largely in drought.
- Extreme-exceptional drought over “hot spot” region of L-A feedbacks.
- Much of the eastern US wetter than average.
- Could this exacerbate the drought? Is this a potential source of sub-seasonal-seasonal predictability?



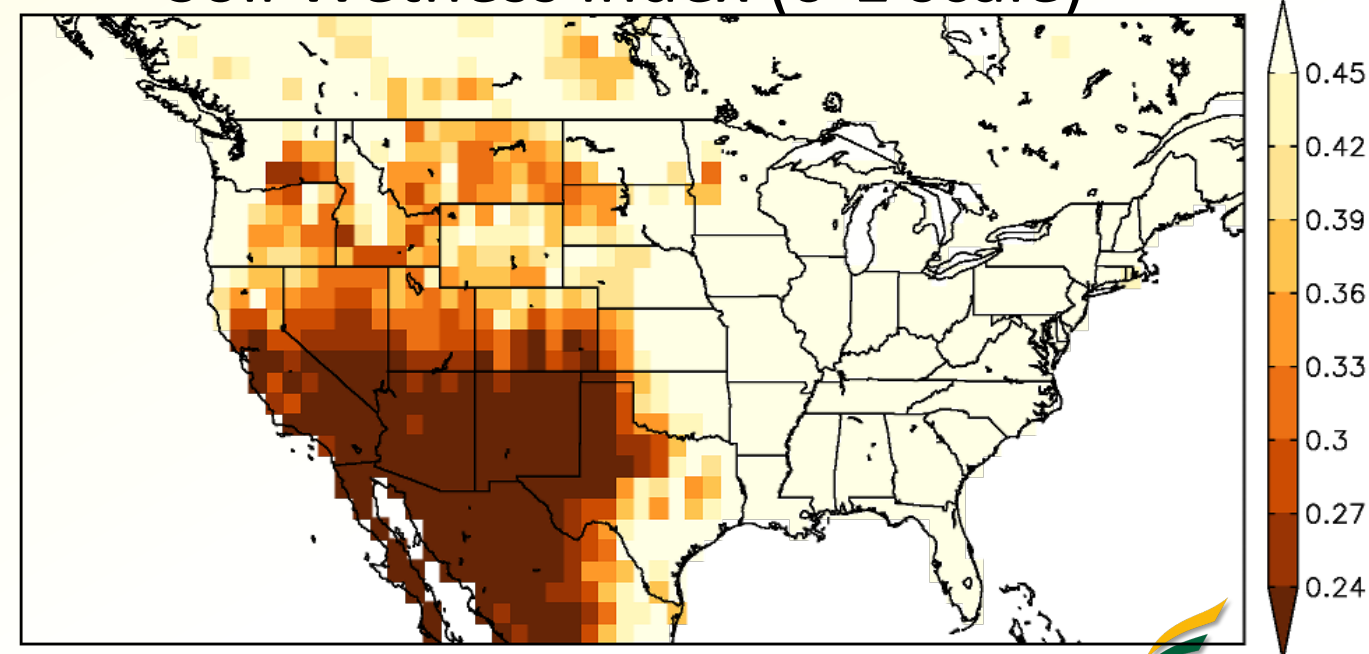
The Model Situation

GLDAS Sfc Soil Wetness 1-5 May 2013

Anomaly (% of normal)



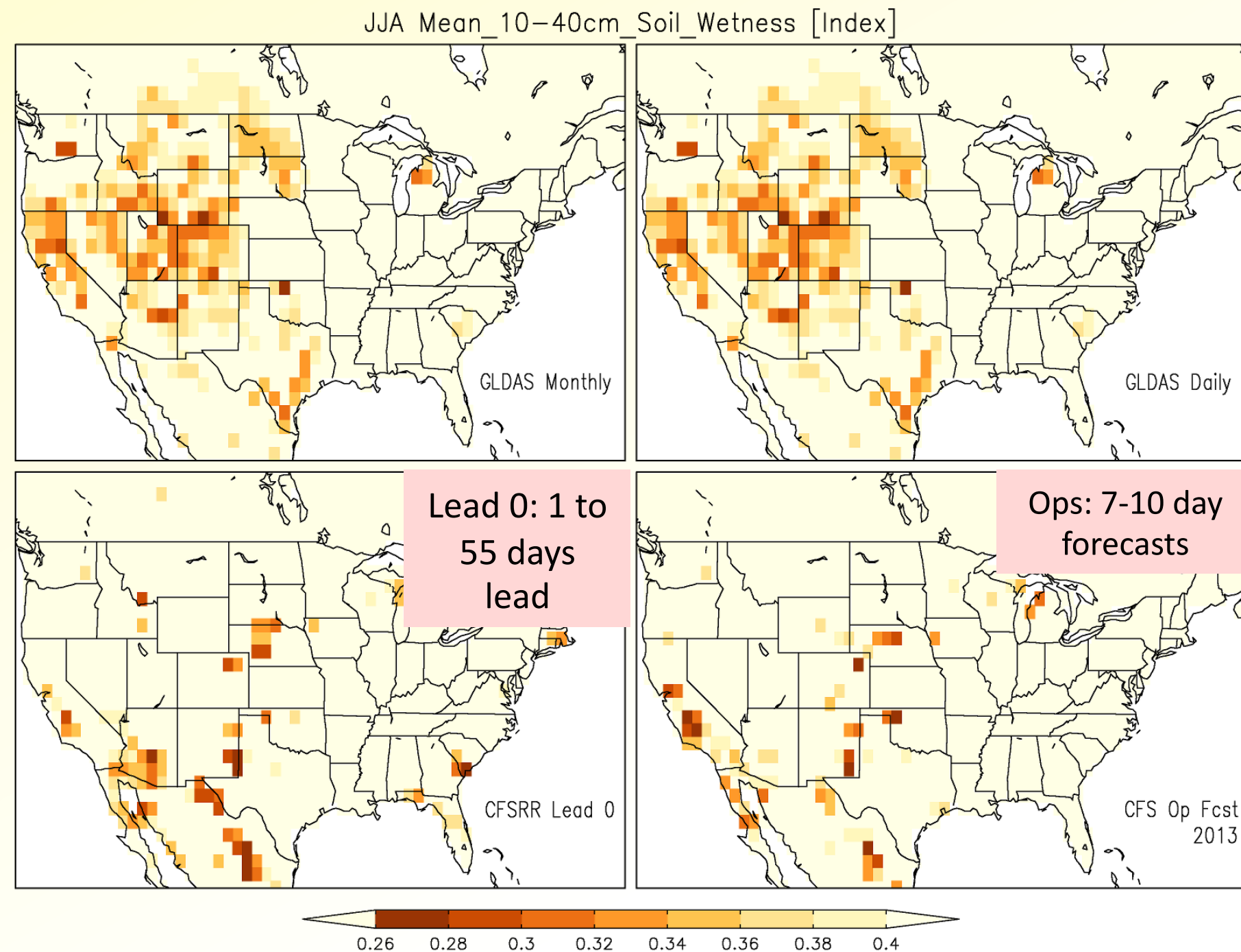
Soil Wetness Index (0-1 scale)



- Dry soils over the west, wet in the east; zero-anomaly line displaced west w.r.t. drought monitor
- This results in an **intensified soil moisture gradient**
- Implications for land surface feedbacks....

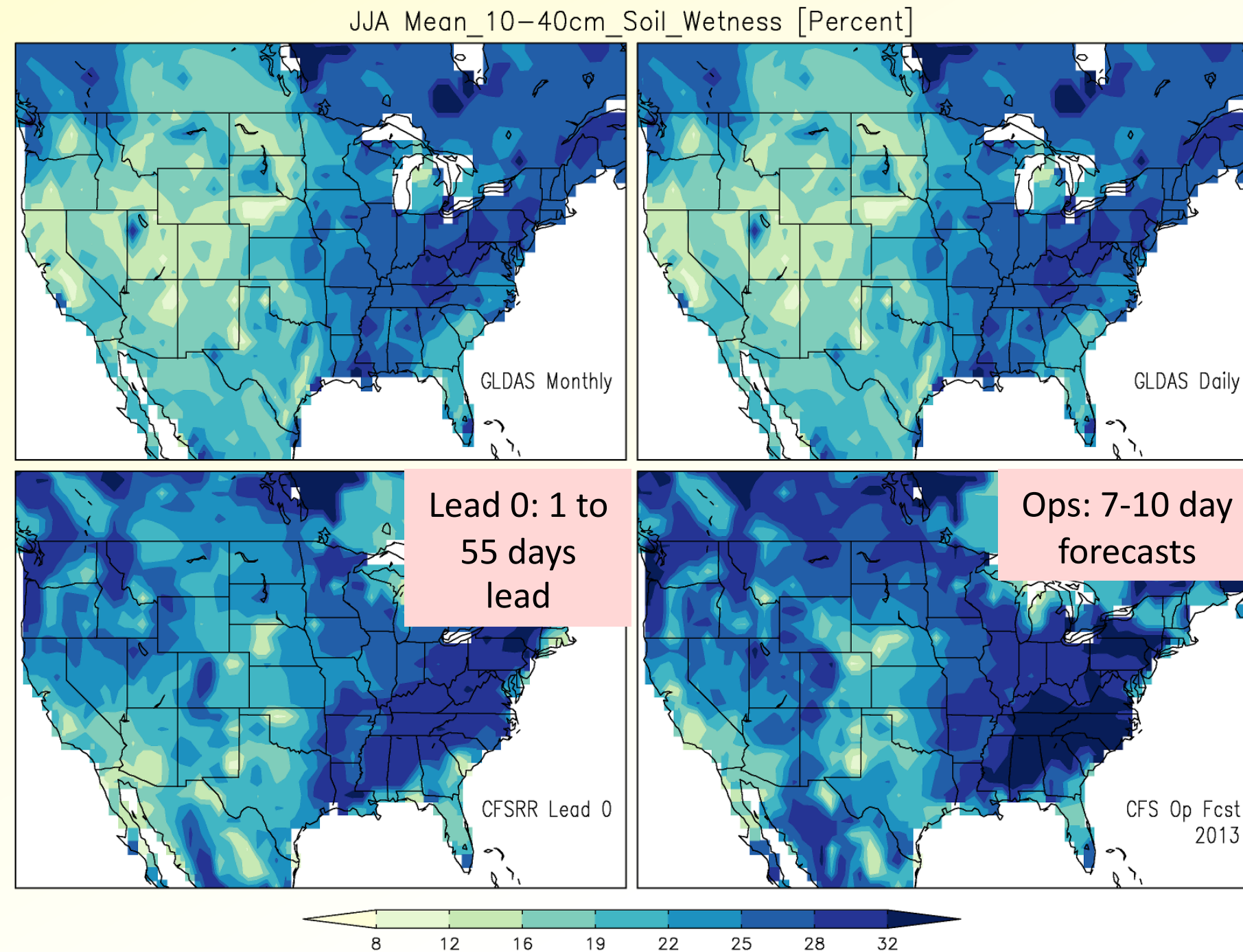
Not Much Potential Sensitivity

- Soil moistures in the prime sensitivity ranges confined to the western US in offline GLDAS (top)
- **Very few points in the coupled CFS (bottom)**
- *Monthly data left (GLDAS & CFSRR), daily right (GLDAS & operational forecasts)*



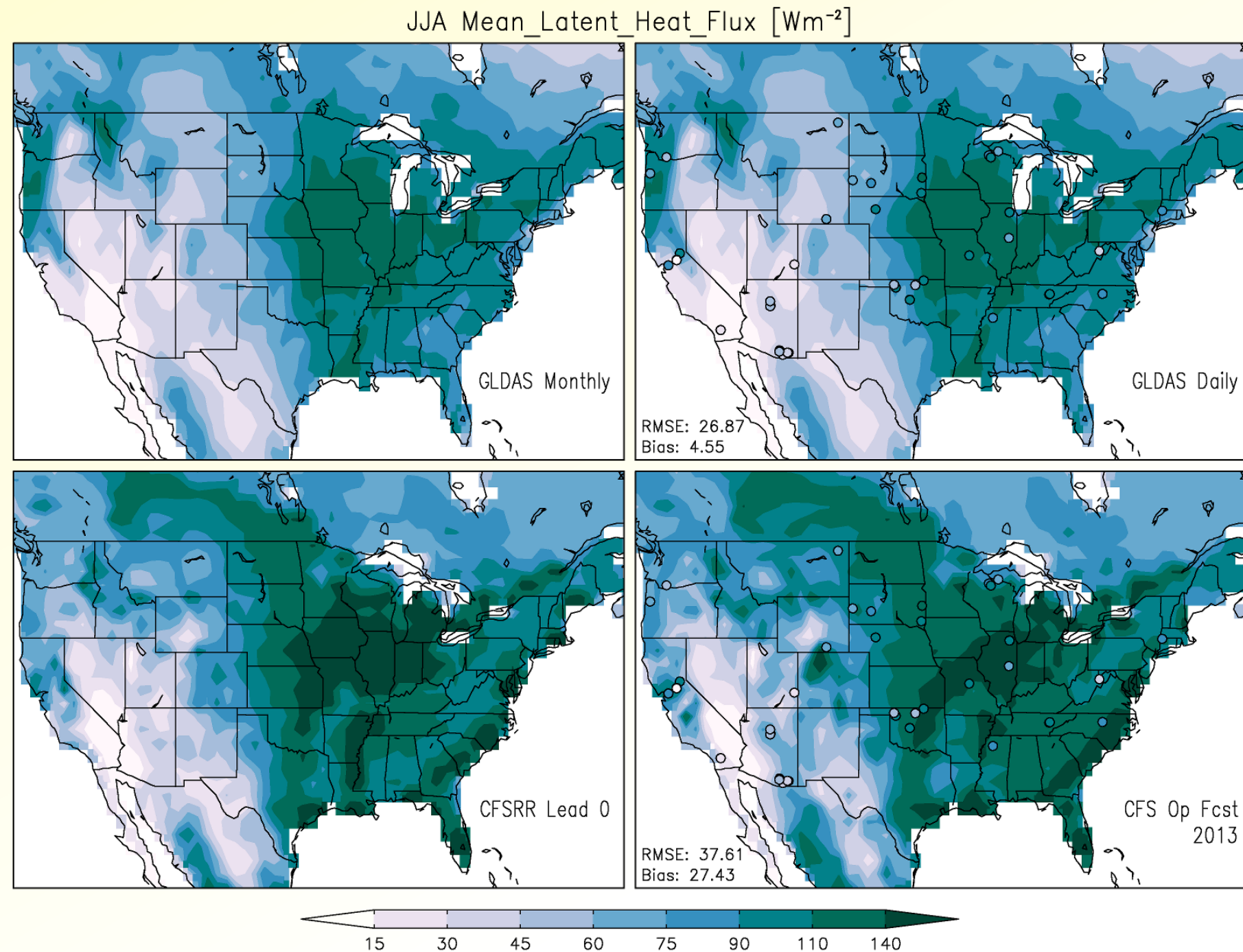
Soil moisture 10-40cm layer

- Sub-surface SM **much wetter** in coupled mode than GLDAS – especially noticeable in the west.



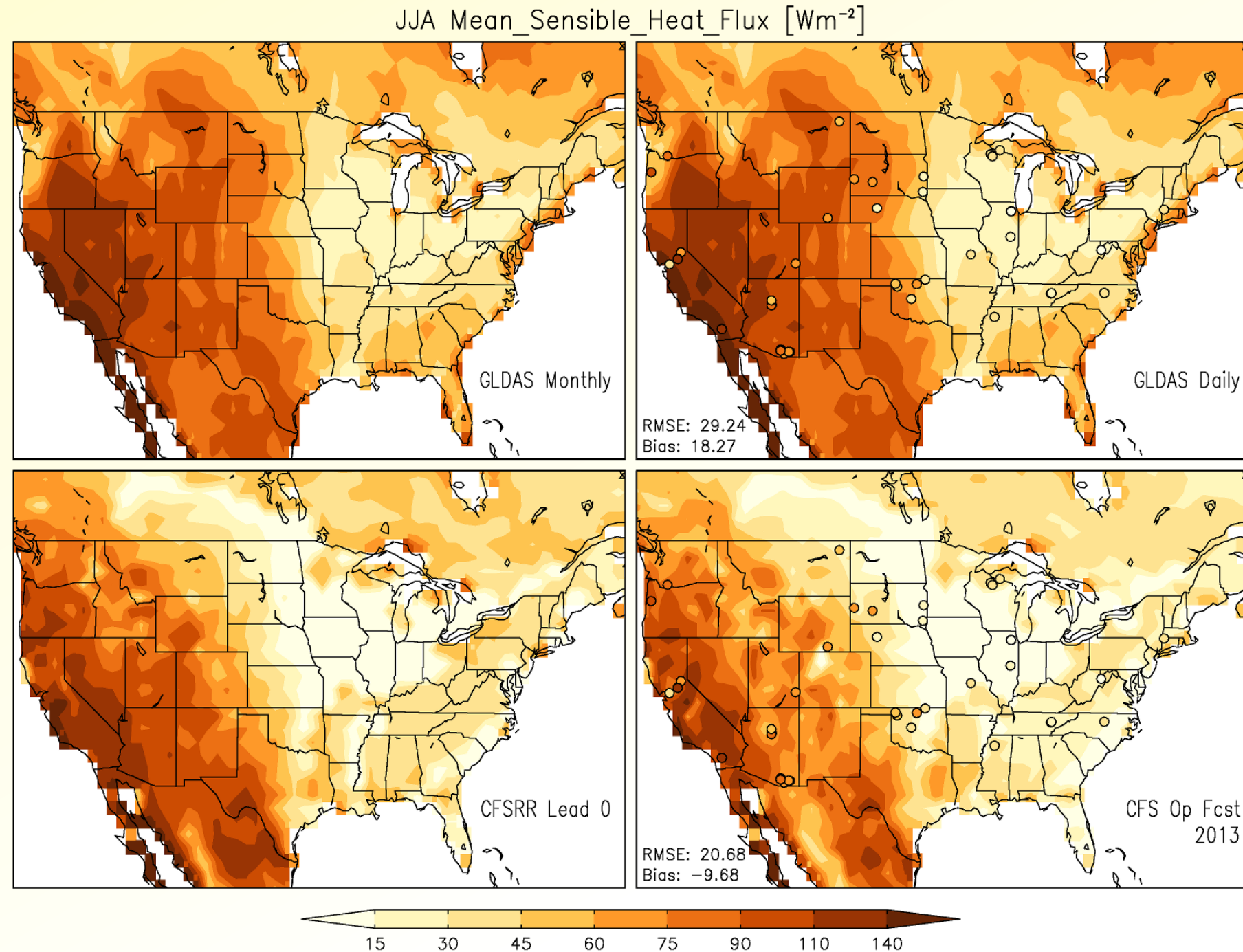
Latent heat fluxes

- Circles are AmeriFlux observations.
- CFS consistently higher than obs.
- Not uncommon – many GCMs exhibit excess evaporation over land, typically driven by net radiation errors.



Sensible heat fluxes

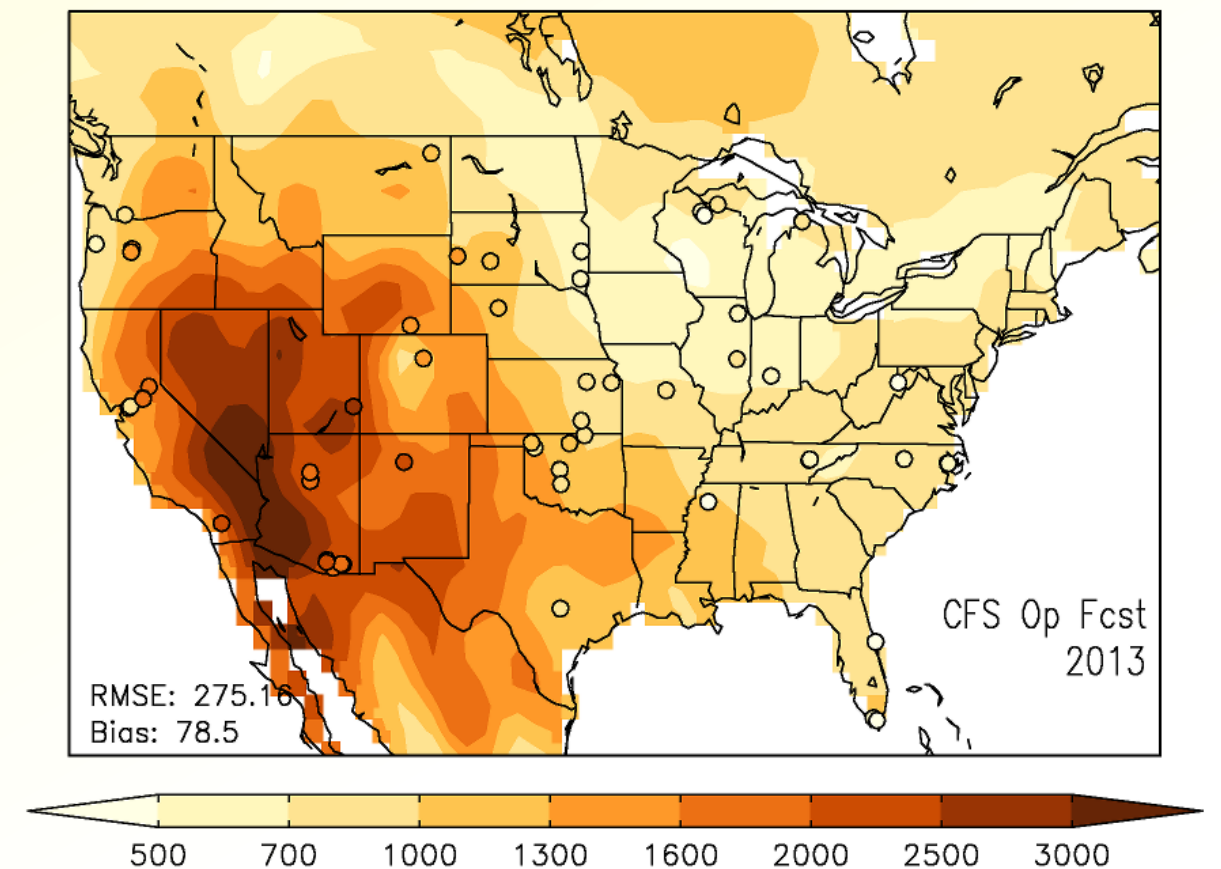
- Essentially zero over much of Midwest in CFS.
- This seems to cause problems for boundary layer simulation (shown later)



Lifting condensation layer

- Calculated as linear function of 2m dew point depression (surrogate for PBL).
- Continental scale gradients and local mean depths are not far from “observations” based on 2m T , T_d .

...But, **variability statistics are quite different.**



Coupling Index

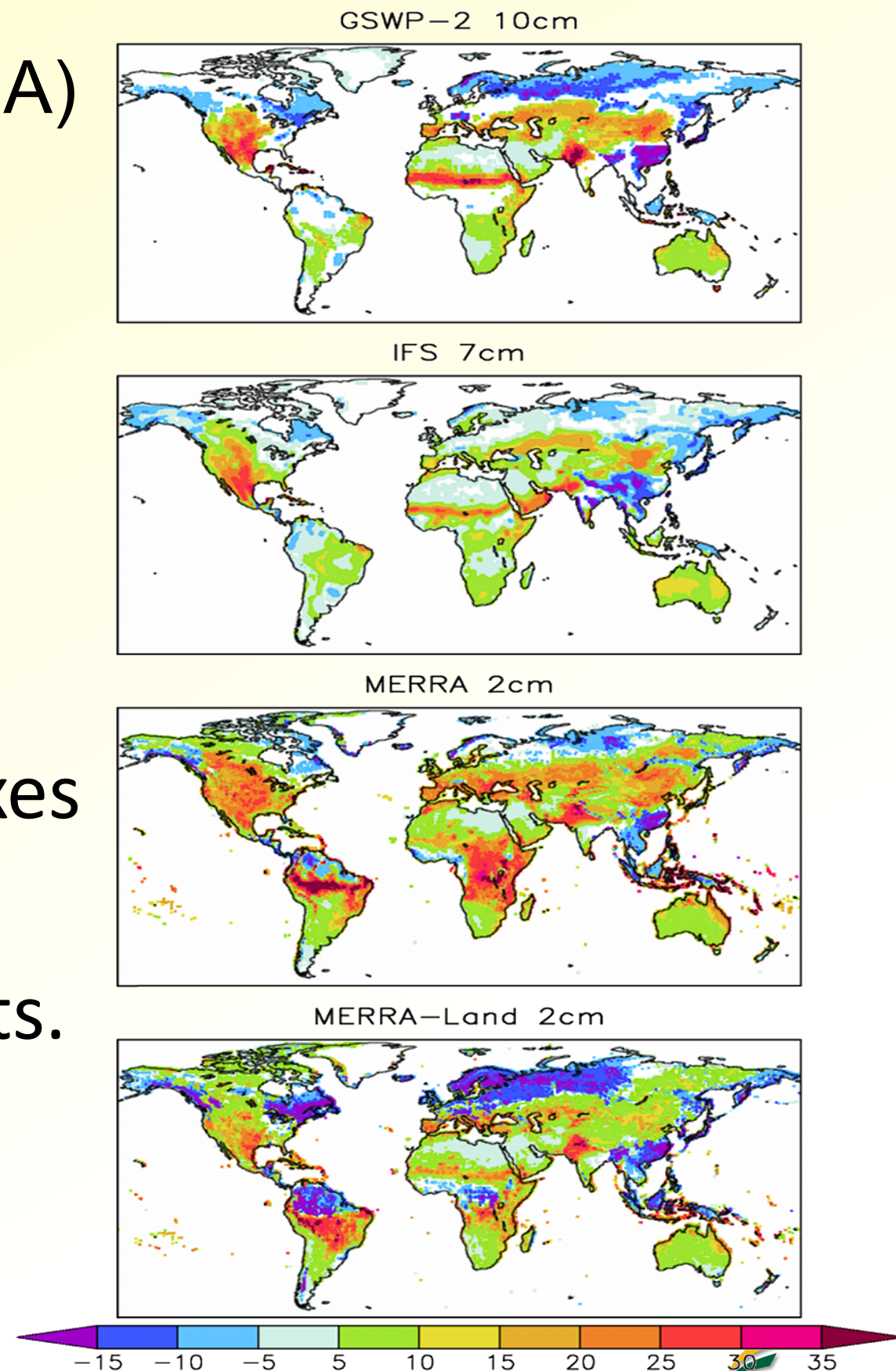
I_{LH} (JJA)

- For surface flux Φ , coupling to soil wetness W is:

$$I_{\Phi} = \frac{\partial \Phi}{\partial W} \sigma_W = r(\Phi, W) \sigma_{\Phi}$$

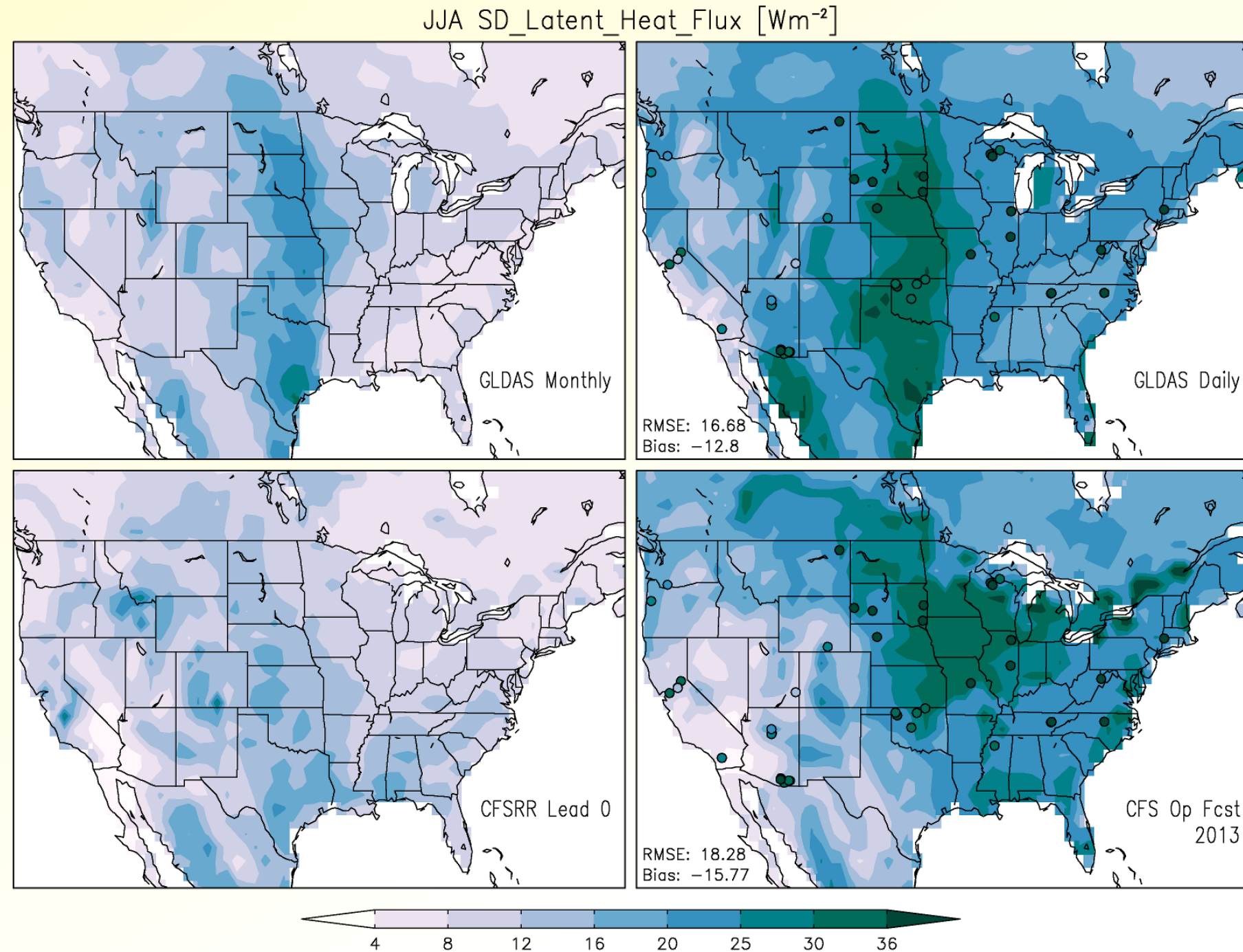
- Applied to sensible or latent heat fluxes (or between fluxes & PBL!)
- Bears strong resemblance to hot-spots.
- Units are same as the flux.

Dirmeyer, 2011: *GRL*, L16702.



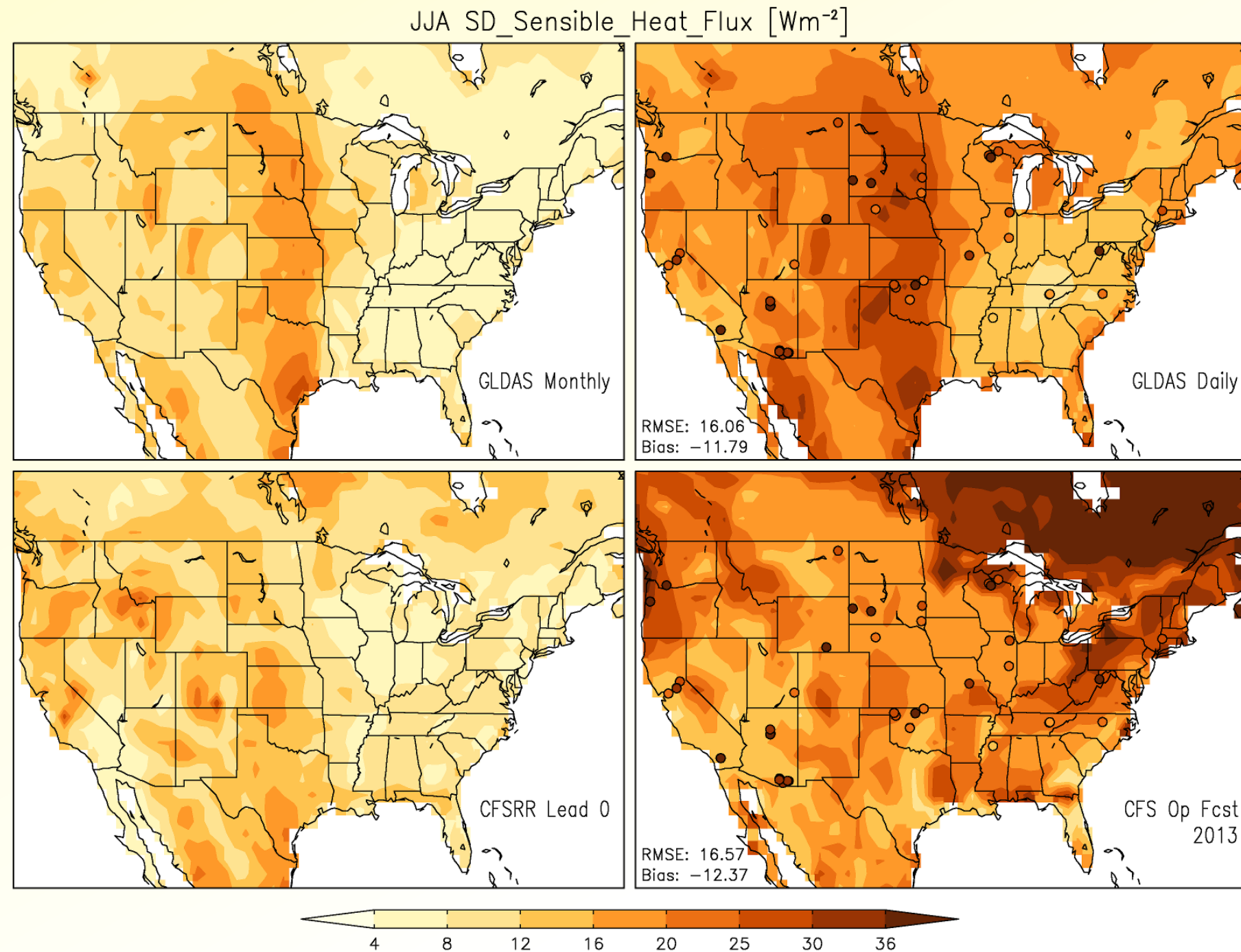
Latent heat flux variability

- Monthly σ lower than daily – obviously.
- GLDAS daily & CFS forecasts have different patterns
- Both have **much lower day-to-day variability than observed.**
- An issue for coupling indices...



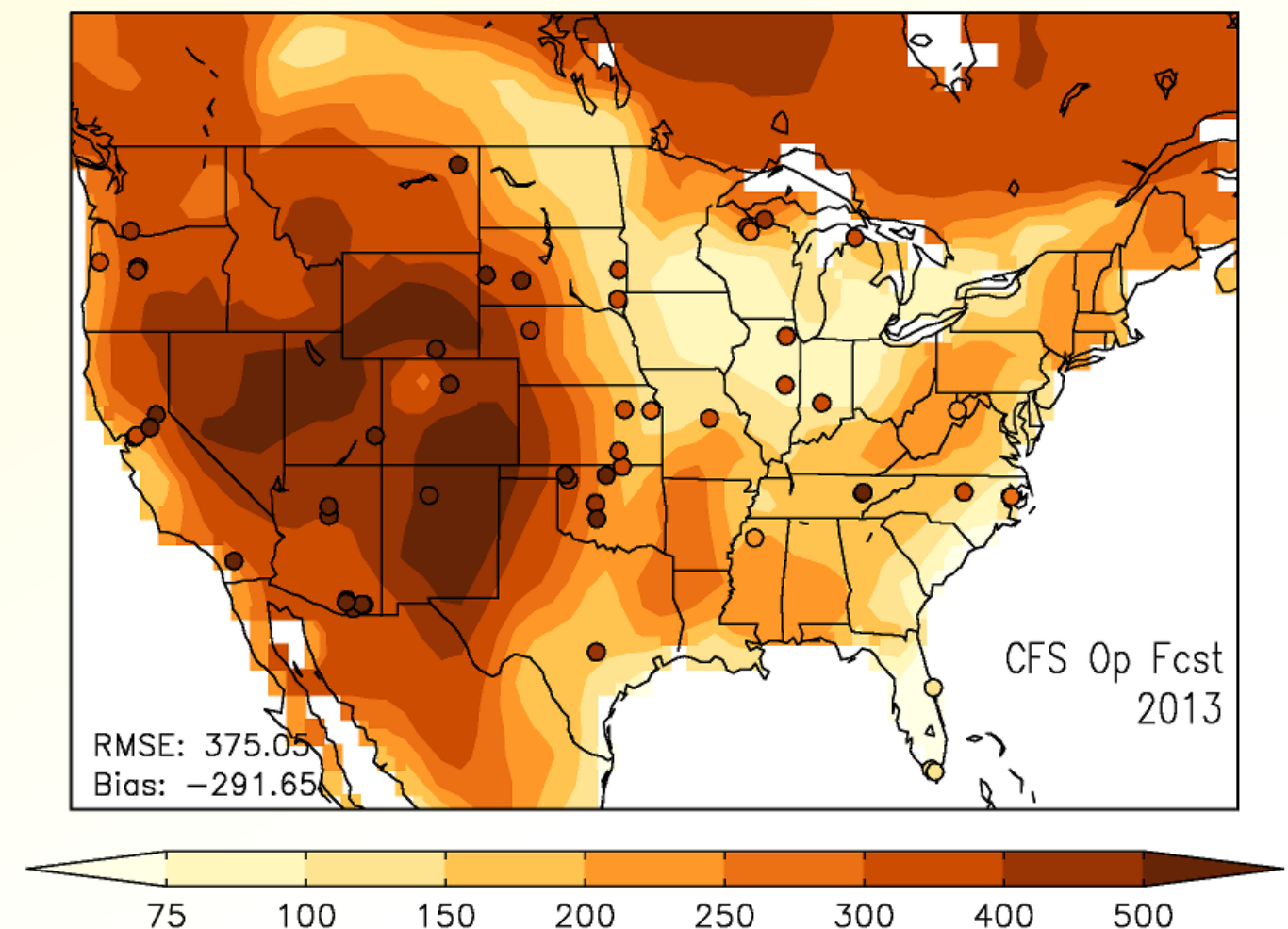
Sensible heat flux variability

- Comparing dailies, again too little variability everywhere.
- Now the **operational model's continental pattern looks nothing like the others, expectations.**



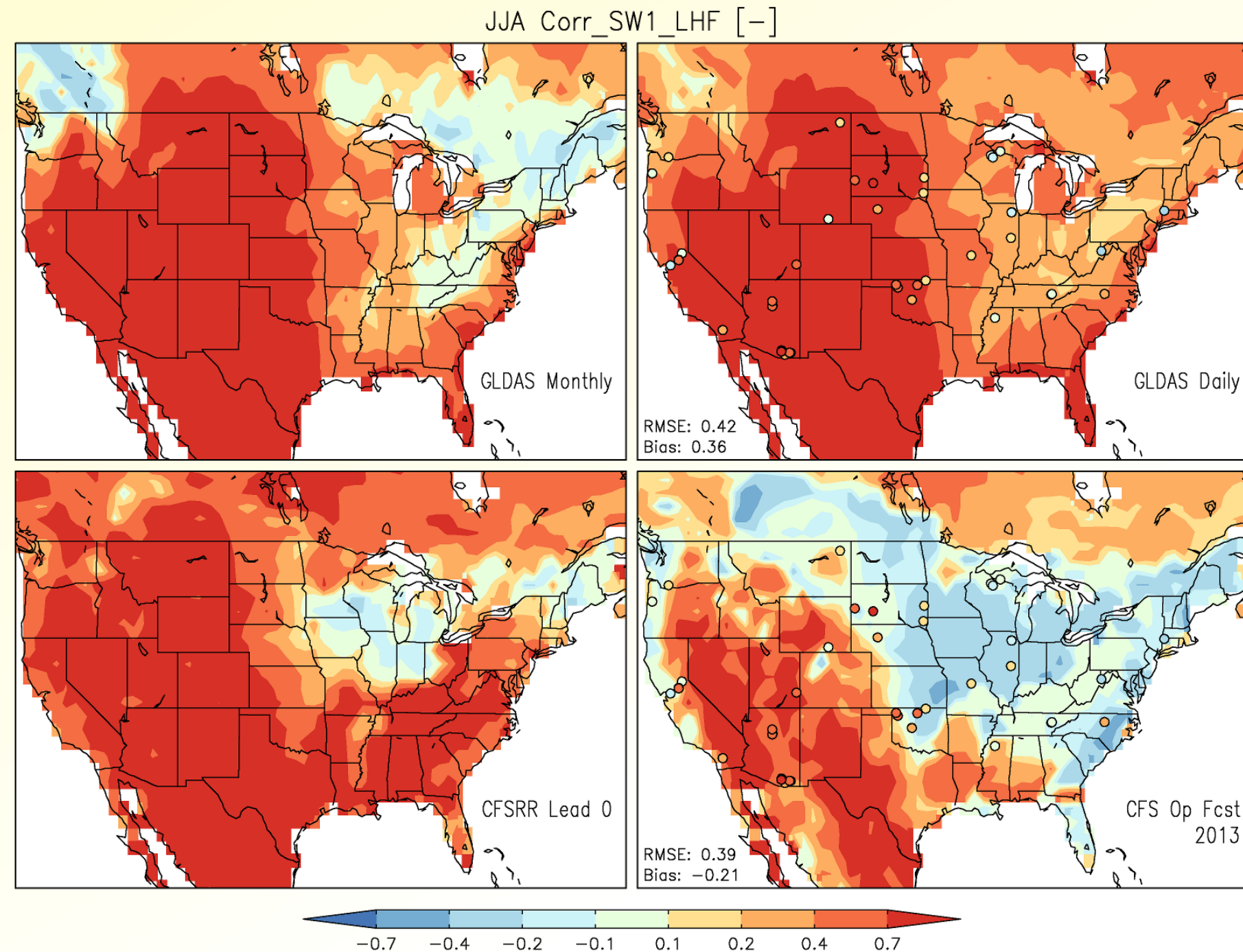
LCL variability

- Signature of sensible heat vagaries is quite evident in the operational forecast model (sensible heat flux builds the boundary layer – LCL is a good proxy for PBL depth).
- Day-to-day variations are way under-forecast across the US.



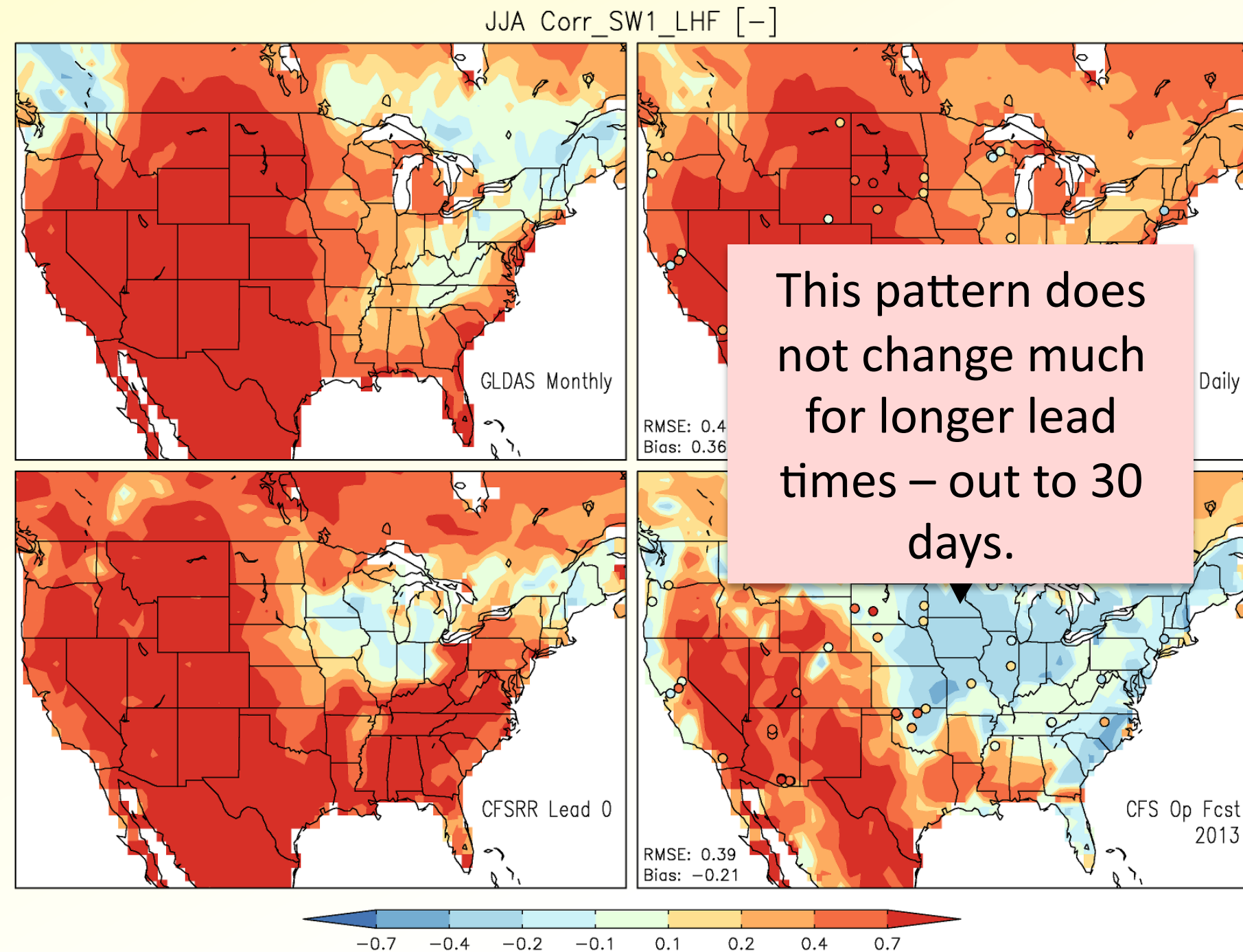
Correlation: SM1 vs. LH

- Theory: positive => feedbacks; negative => no feedback, land driven by atmosphere.
- Operational model is **less coupled than observations suggest.**
- GLDAS (offline land model) is too strong.



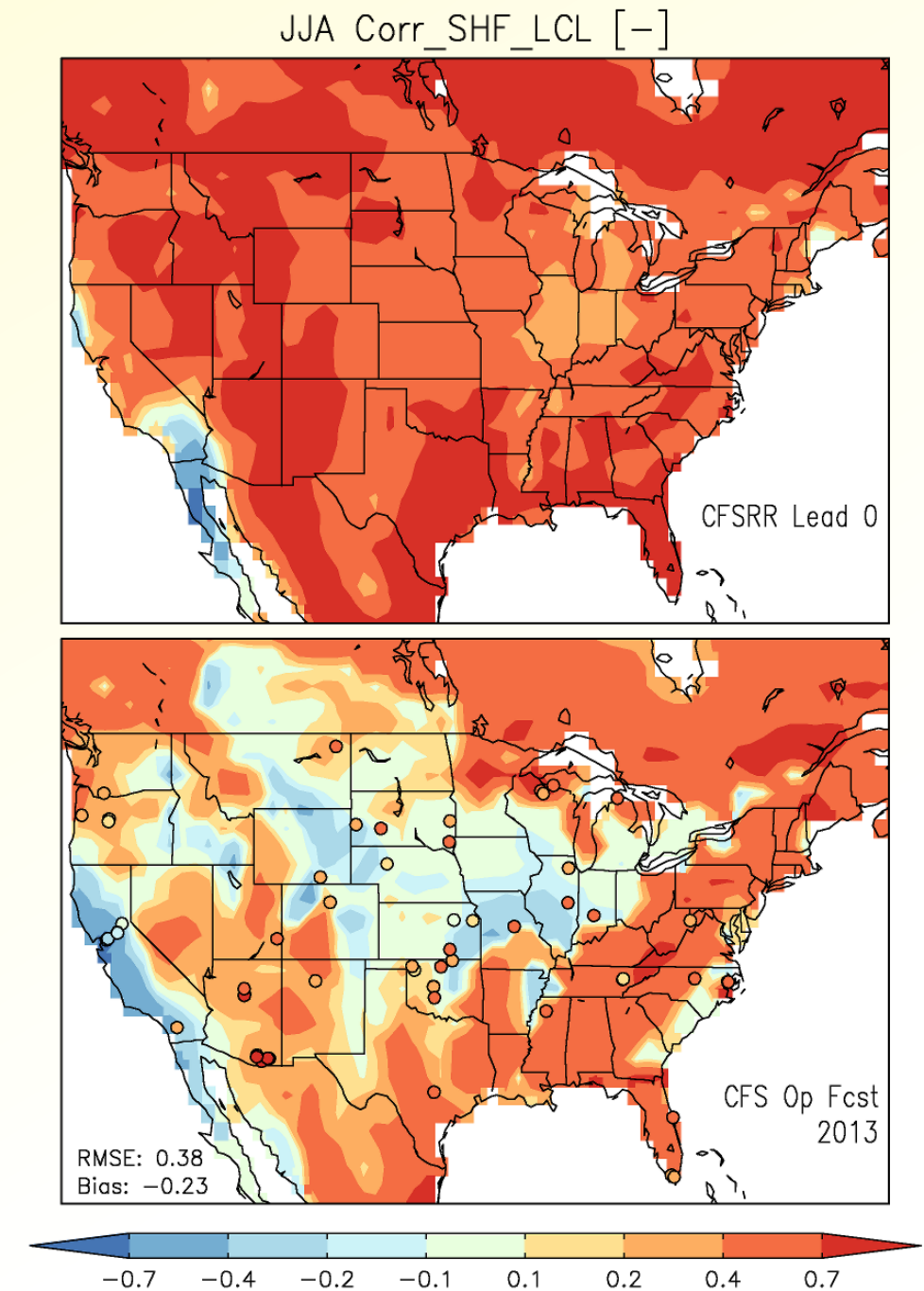
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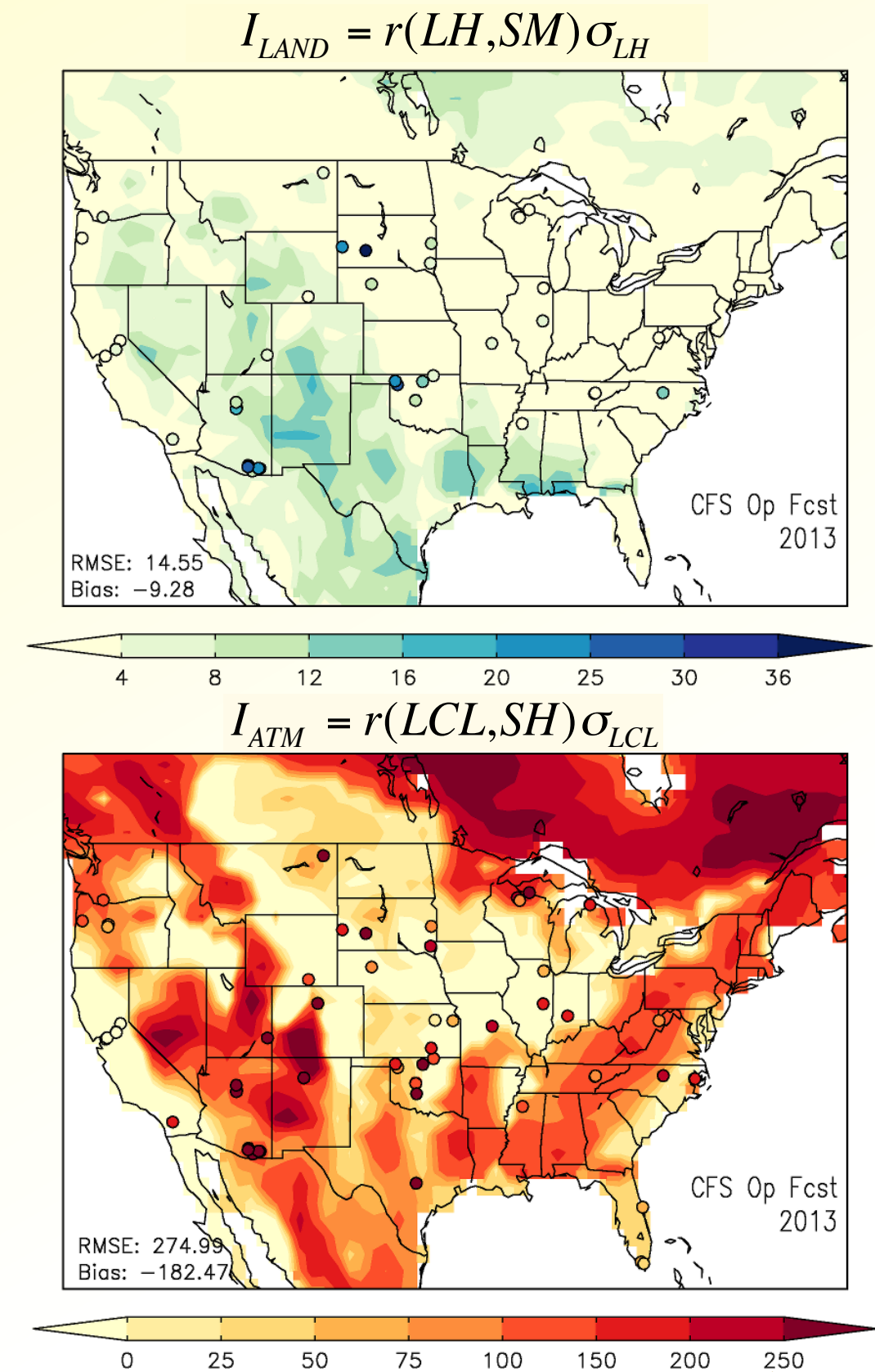
LCL Correlation with SH

- Here all the biases compound.
- In reality, negative correlations only occur where marine air/circulations dominate (e.g., coastal California), or where baroclinic frontal passages control LCL and SH (winter).
- Operational model shows **almost no forcing of boundary layer by surface heating over plains and ag areas**, but do over Canada (can't blame fronts).



Coupling Indices

- Because of the weak/misplaced correlations and variance, both the land leg and atmospheric leg of the feedback cycle are lacking.
- Noah/GFS soil moisture exhibits insufficient control on surface fluxes, which also show too little day-to-day variance, and little impact on boundary layer growth over key regions (Central US).
- **This is a coupled problem!**



Conclusions

- GLACE-2 (and other less extensive experiments) have shown that realistic land surface initial states can contribute to improved sub-seasonal forecast skill.

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- Even in GLACE-2, only a few GCMs showed this effect – most **models are lacking “something”** necessary to harvest this source of predictability.

Conclusions

- GLACE-2 (and other less extensive experiments) have shown that realistic land surface initial states could contribute to improved sub-seasonal forecast skill.
- Even in GLACE-2, only a few GCMs showed this effect – most models are lacking “something” necessary to harvest this source of predictability.
- CFS is one of these models – more realistic coupled land-atmospheric behavior (links from surface states to fluxes to boundary layer to clouds/convection over land) is needed.

Coupled L-A model development!

Thank You.

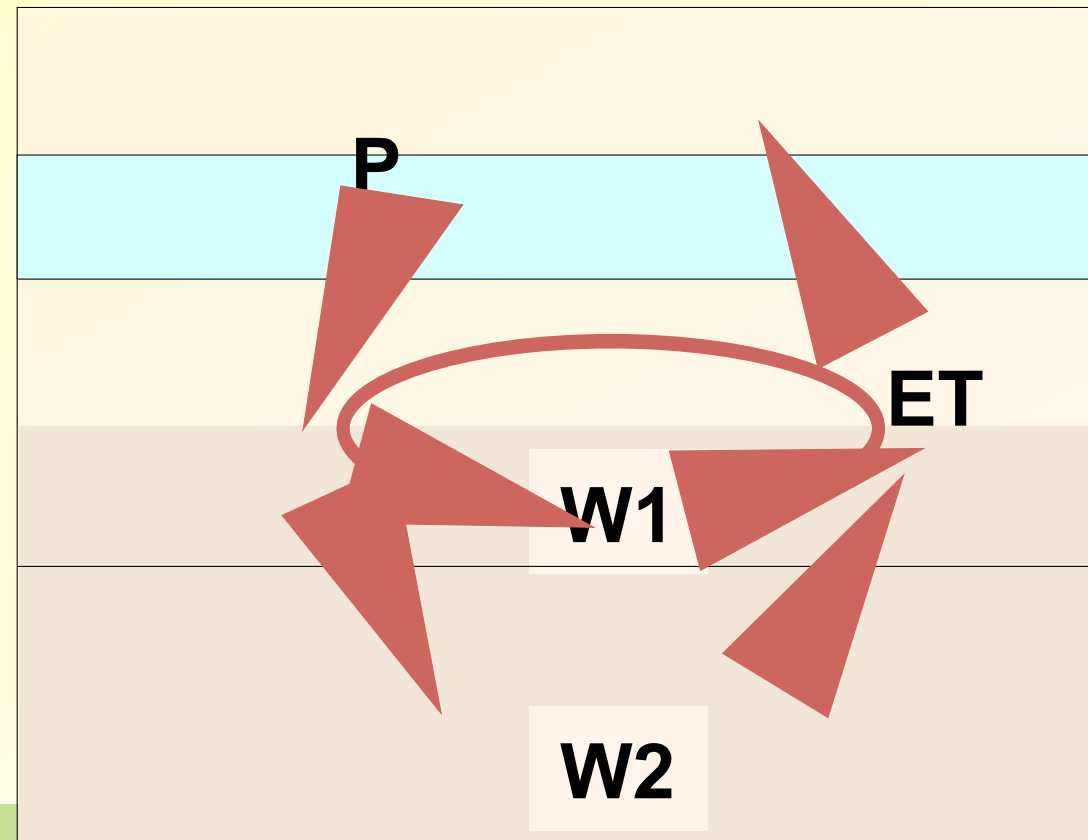
Theory:

Arid regime:

ET (mostly surface evaporation) is very sensitive to soil wetness variations, but the dry atmosphere is unresponsive to small inputs of water vapor.

Arid

Coupled Feedback Loop



Humid regime:

Small variations in ET affect the conditionally unstable atmosphere (high moist static energy), but deep-rooted vegetation (transpiration) is not responsive to nominal soil wetness variations.

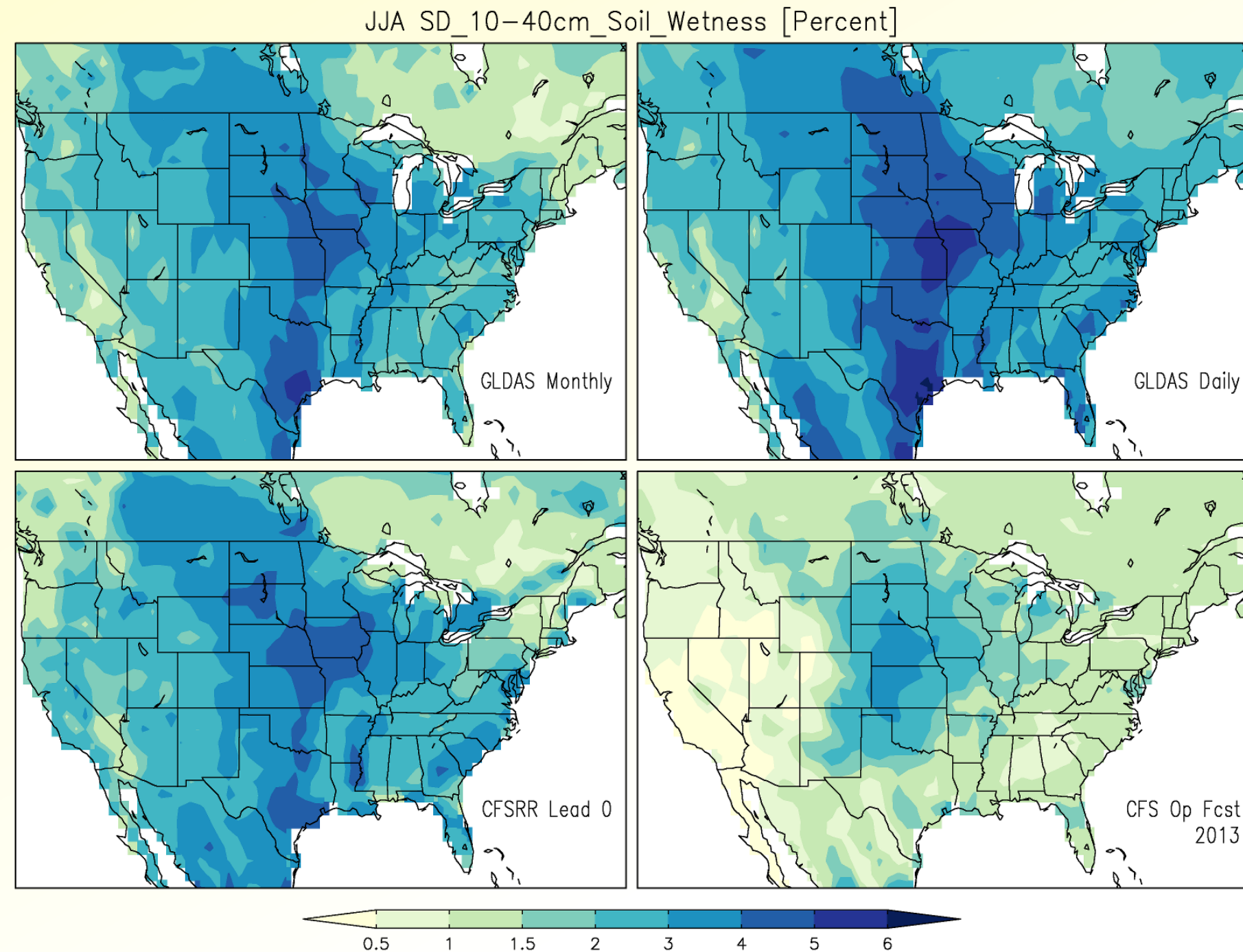
ET → P

In between, soil wetness sensitivity and conditional instability both have some effect.

Humid

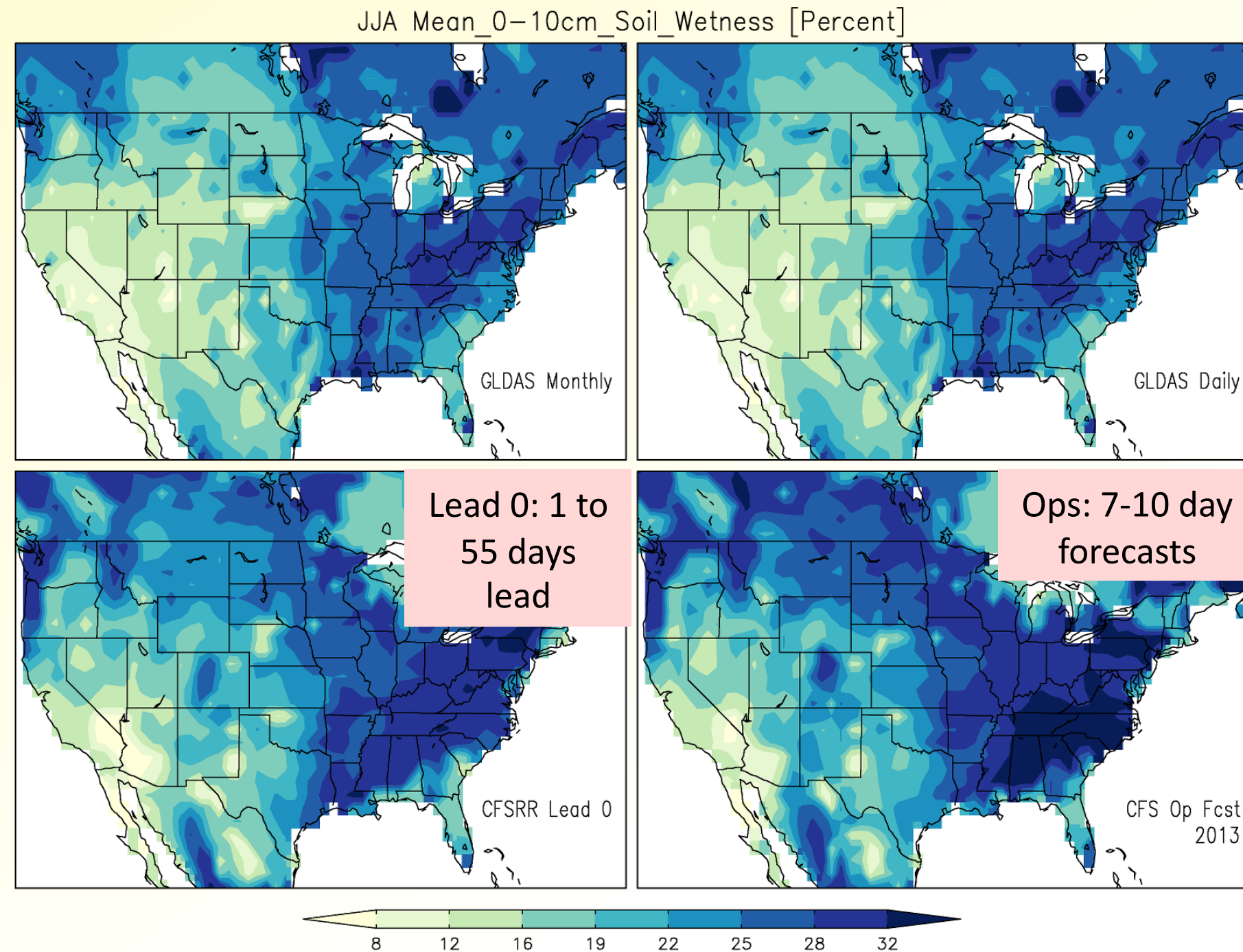
Standard deviations – 10-40cm SM

- Not exactly apples/ apples – CFS Op Fcst has no interannual variability, GLDAS has no intra-ensemble variability.
- All put the greatest JJA variability over the “hot spot” – agrees with theory, other models.



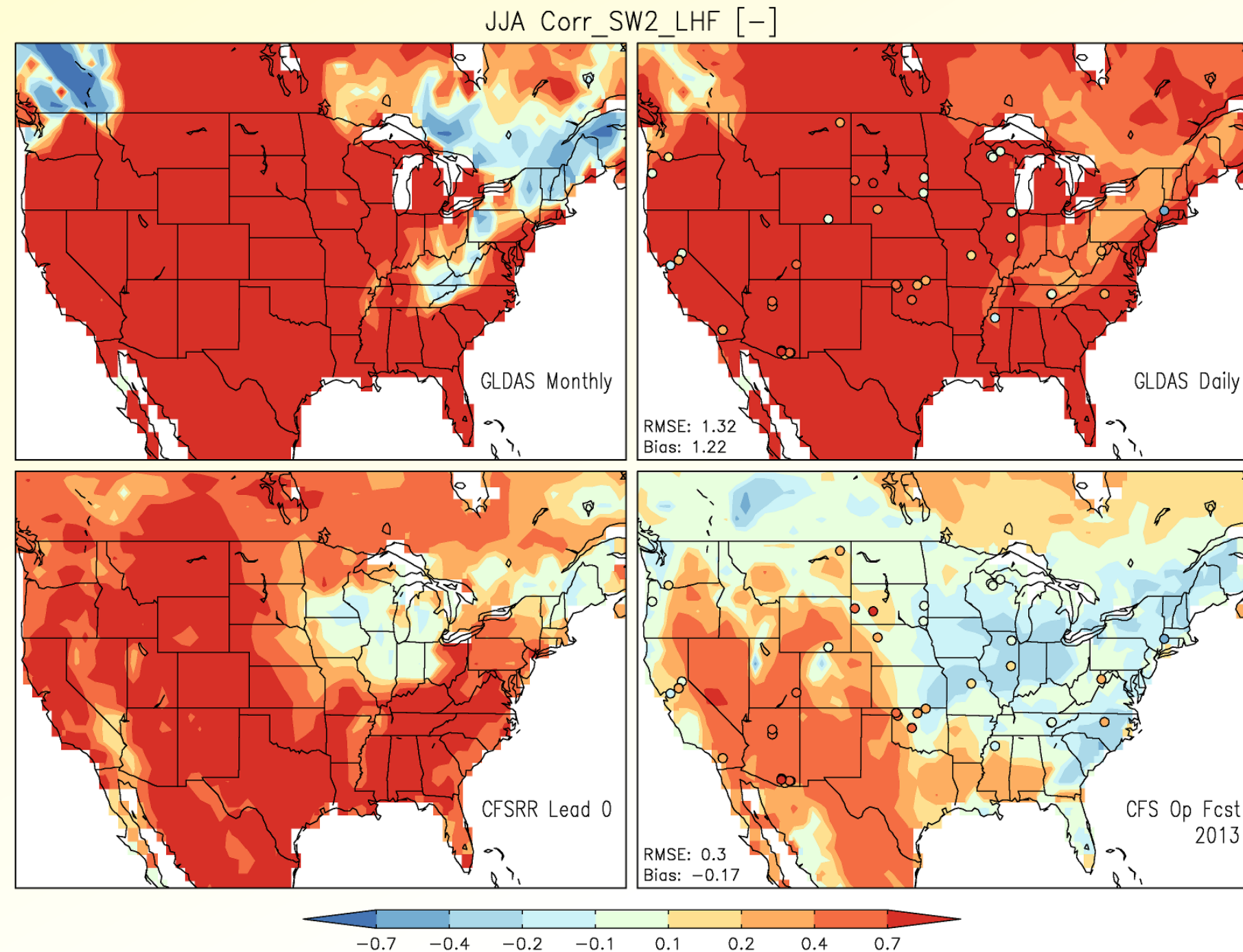
Surface Soil Moisture

- Surface SM shows expected E-W gradient
- **Coupled model is wetter**, especially when model is unconstrained by data assimilation



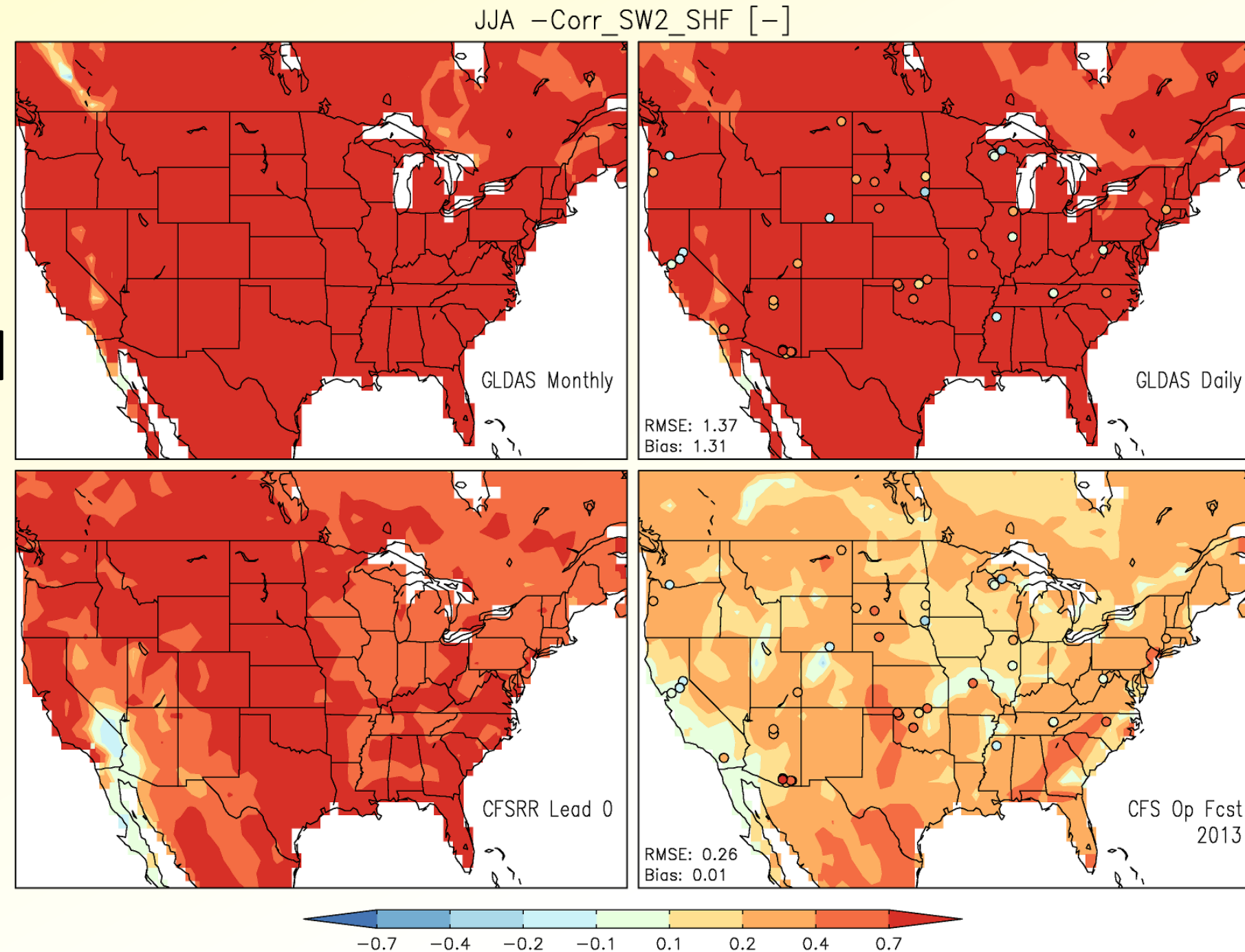
Correlation: SM2 vs. LH

- Similar to surface SM – a bit higher correlation over arid regions.
- Observations suggest usually weak positive correlations where GLDAS has strong positive, coupled model has negative.



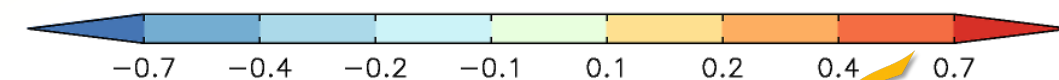
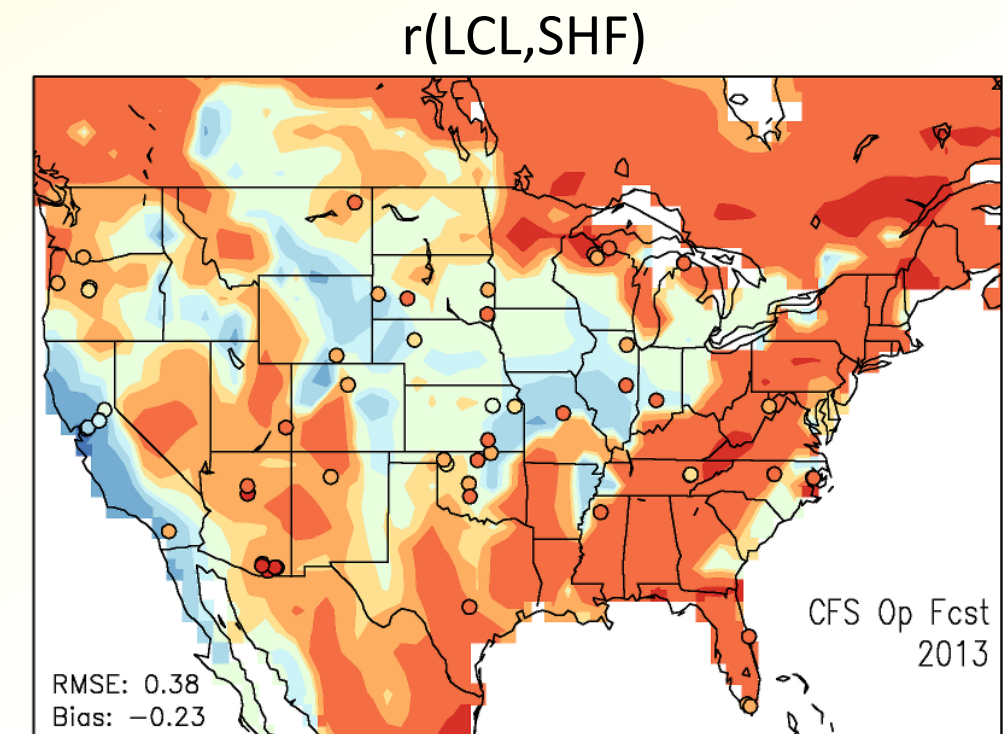
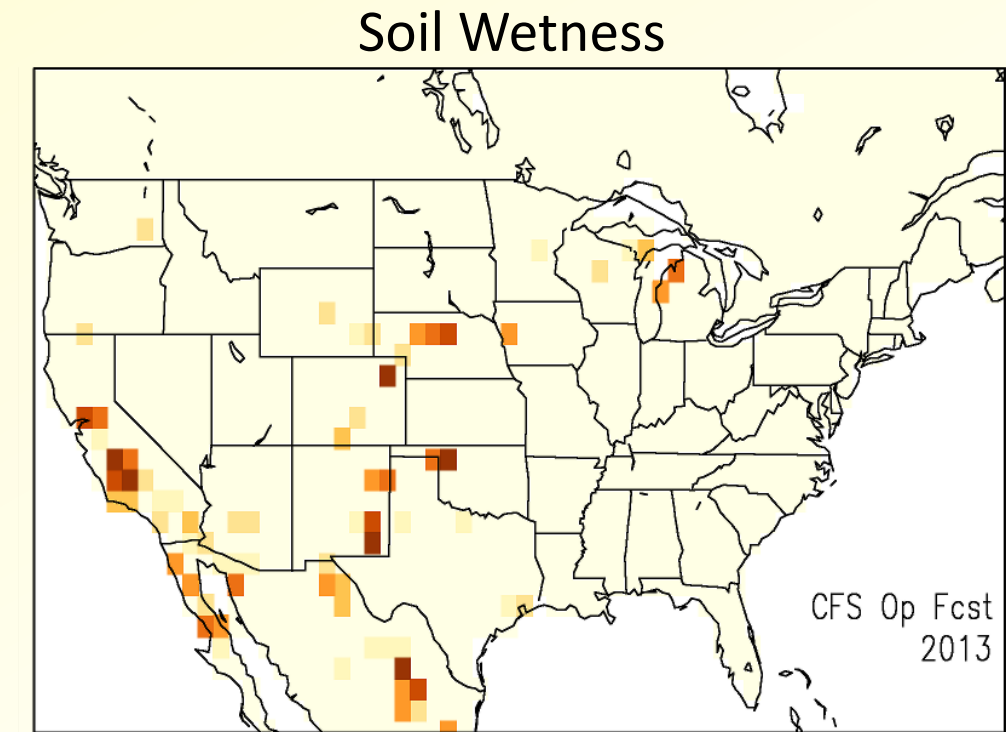
Correlation: SM2 vs. $-(SH)$

- The strong correlation suggested by Betts is not so dominant in the observations (1d vs. 5d (vs. monthly)).
- GLDAS much too strong; operational forecasts (daily data) no bias, but **not well positioned**.



Synthesis

- The region where Noah soil moisture is in the range to affect surface fluxes corresponds largely with the area where the GFS atmospheric model boundary layer does not appear to be driven by surface sensible heat flux.
- This is a coupled problem.



October floods

- Colorado (top) and New Mexico (bottom) 9-16 September total precipitation – CPC-Uni (1979-2012; circle=2013) and CFS operational forecasts at leads out to 45 days).
- CO precipitation bracketed by ensemble, NM precipitation not.
- “Something” happens 2 weeks in advance that moves CO envelope above climatological distribution.

